Sediment Formation in Nearshore Environments: Strength, Rheology, Microstructure, and Stability

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LONG-TERM GOALS

Our goals are to understand how geotechnical and physical properties develop in marine sedimentary deposits on continental margins and how these properties influence sediment transport processes and the development of geomorphology. Our studies include predicting stability of sediment on the continental shelf and slope, providing input parameters for models of sediment transport and deformation, and distinguishing morphologic features caused by slope failure from those caused by other gravity-driven processes. Our studies also include improving our understanding of the transition between initial slope failure and the development of debris flows and turbidity currents and predicting the rheological properties that determine the dynamics of such flows. We applied this approach to the EuroSTRATAFORM project, within which we collaborate with scientists seeking to model the formation and alteration of nearshore sedimentary bodies.

OBJECTIVES

Our main objectives for FY06 focused on: (1) understanding the ways in which sediment bodies develop shear strength and structure; (2) testing shear strength development models in controlled environments, (3) furthering the development of concepts of seismic and biologic strengthening; (4) assessing the signatures of catastrophic events to determine whether they are produced by deformational (landsliding) or depositional (turbidity current sediment waves) processes, with a particular attention to the Cap de Creus Canyon; (5) providing the scientific community with rheological properties of fully deformed sediment masses to be used by turbidity current and debris flow modelers.

APPROACH

Our research focuses on the geotechnical changes that occur as sediment is buried under the seafloor. These changes include the direct influence of burial, the impact of repeated seismic shaking (seismic strengthening), and the effects of biological activity (biological strengthening). Part of this analysis also relies on obtaining information on non-bioturbated, normally consolidated sediments via SEDCON (SEDimentation-CONsolidation) tests which can be integrated into geotechnical profiles as a reference curve enabling us to extract the relative influence of bioturbation and/or seismic strengthening. We use samples taken in connection with the EuroSTRATAFORM project in the Gulf of Lions as well as synthetic sediment produced in the laboratory (SEDCON). We also determine the sediment microstructure using SEM techniques and mercury microporosimetry. We compare field

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geotechnical and microstructure profiles with those developed in the laboratory following the application of compressive loads. This will help ascertain the significance of seismic and biological strengthening in altering geotechnical profiles. Some of the observed behavior, when evaluated on cores, may have been influenced by the effect of gas dissolution leading to sample disturbance. This is being evaluated by coupling CATSCAN imaging and geotechnical properties of the cores obtained as part of EuroSTRATAFORM and PROMESS projects with *in situ* penetration test results available as part of the PROMESS project.

Key individuals, at Laval: Jacques Locat, Mylène Sansoucy, Geneviève Cauchon-Voyer, Serge Leroueil, and Pierre Therrien: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation; at the USGS: Homa Lee, Dianne Minasian, Pete Dartnell, Kevin Orzechf and Brad Carkin: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS, and strength development from seismic shaking. Partners in Europe are N. Sultan (France), M. Canals and R. Urgeles (Spain), and F. Trincardi (Italy). D. Orange, partner in EuroSTRATAFORM has also been participating in our work.

WORK COMPLETED

During FY 06, we completed work related to geotechnical (Figure 1) and microstructural (Cauchon-Voyer et al. 2005) characterization of PROMESS deep boring samples along with geotechnical profiles of selected cores from the Cap de Creus Canyon (CCC, Figures 2 and 3) collected as part of the October 2004 EuroSTRATAFORM cruise (leg 2). All the CCC cores were logged onboard the Oceanus using the

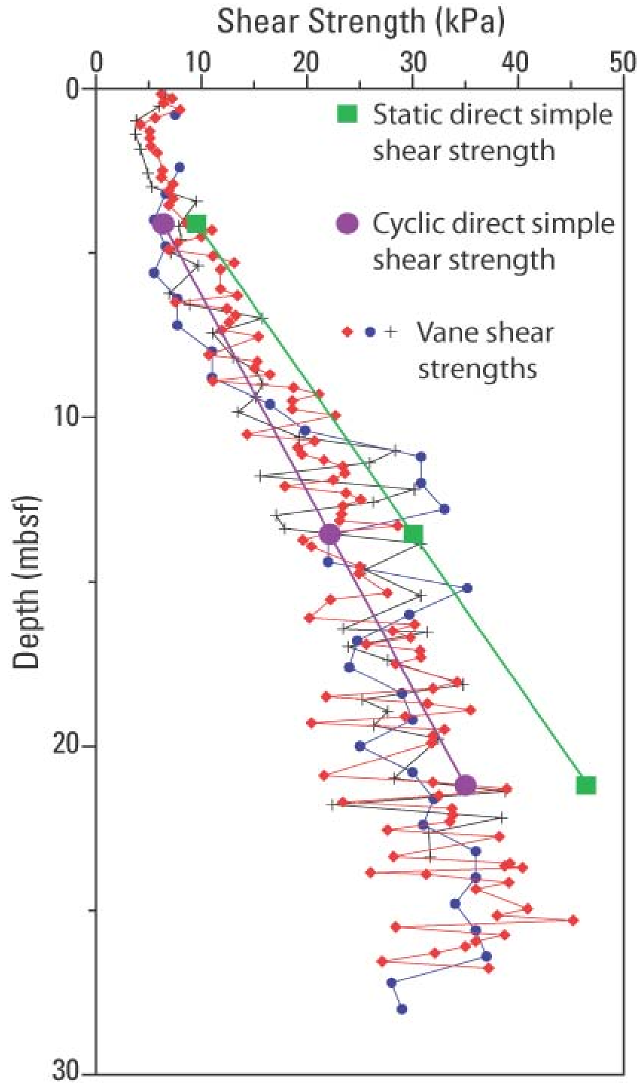

Figure 1. Shear strength profiles for the Adriatic PROMESS site (PRAD2) showing the relation between measurements obtained using different techniques. Direct simple shear testing conducted at the USGS partly corrects for coring disturbance which affects vane shear measurements and also allows us to evaluate the influence of cyclic (earthquake) loading. Vane shear testing was conducted by our European partners.

USGS Multi Sensor Core Logger, and deck work also included fall cone testing and water content measurement. Once at Laval, all the CCC cores were run through the CATSCAN (Sansoucy *et al.* 2005). Seven, approximately 25 cm long subsections from the deep PROMESS borings in the Adriatic Sea and Gulf of Lions were provided to the USGS and Laval by our European collaborators. These subsections were analyzed in detail with the CATSCAN system in order to determine the effect of gas disturbance on the sampling quality and strength. Work on these PROMESS cores also included detailed physico-chemical, mineralogical, microstructural, porosimetry, and geotechnical analyses (Cauchon-Voyer et al. 2005). Geotechnical testing on CCC cores was conducted both at Laval and at the USGS, and included Atterberg limits, water content, strength tests (intact and remolded) using the Swedish fall cone testing, and cyclic and static direct simple shear tests (at USGS). Rheological tests were carried out on a selected mixture of CCC samples. Work completion in FY06 also included papers prepared for various conferences and journals (Cauchon-Voyer *et al.* 2005; Lee *et al.*, 2005;

Sansoucy *et al.* 2005). FY06 also included the completion of a major contribution to the Master Volume of STRATAFORM (Lee, Locat, *et al.,* 2005, ch. 5).

RESULTS

Our analysis of CCC cores focused on specific sites indicated in Figure 2. The selected area is located on the north side of the canyon in water depths ranging between 280m and 750m. This sector presents evidence of landsliding which has led to the accumulation of debris at the toe of the slope. The headwall escarpment is about 30m high and has a slope of 27°, whereas the failure plane is inclined at about 20° and is about 450m wide. The slope of the debris where sample PCFL-665 was taken is at about 5° reducing to about 1° near the thalweg. Sample PCFL-665 was analyzed to determine the nature of the sediments along with the geotechnical and rheological properties**.** Our primary objective is to understand the development of instability along the canyon wall and also how slope failure influences canyon formation. First we defined the slope profile (extracted from Figure 2) and characterized the slope sediment using various geotechnical tests (Figure 3) either onboard (e.g., multi sensor core logger) or in the lab (CATSCAN and strength profiles). To achieve this, a series of cores were selected along the slope of part of the canyon shown within the white rectangle of Figure 2.

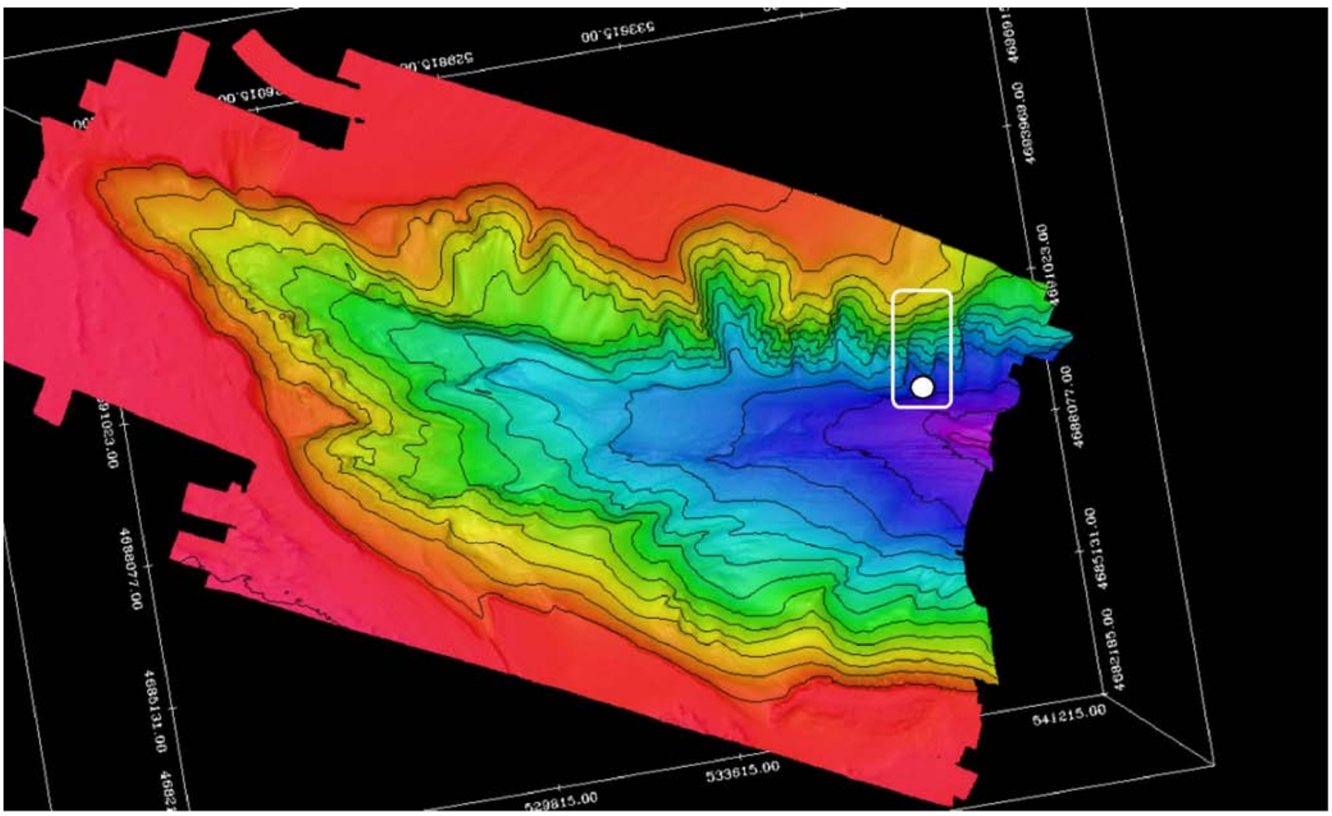

Figure 2. Multibeam image (Orange et al. 2006) of the upper part of Cap de Creus Canyon area, the study site (shown as a white rectangle) and the sample site for the geotechnical profile shown in Figure 3.

The geotechnical profile (Figure 3) illustrates two facies: a homogenous (hemipelagic ?) brownish grey clay with a plasticity index of about 47% and a bluish grey clay of lower plasticity index (24%) and variable water content which is present in the form of clasts reaching about 5cm in diameter and having a water content around 40%. The bluish grey clay is interpreted as corresponding to a debris flow event. At least three events can be identified in the core. The water content, liquidity index and strength profiles are also quite different between the two units. The hemipelagic clay exhibits a typical decrease in water content and liquidity index and an equivalent increase in strength with depth. In the debris flow units, the water content, liquidity index and strength in the fine portion just above the clast layer are nearly constant. Reasons for these differences are being investigated, The geotechnical profile (Figure 3) of this zone suggests that depositional events, such as debris flows and turbidity currents, occur frequently, under a more or less erosive regime. The geotechnical and rheological properties have been used for failure (sliding conditions) and post-failure analyses (mobility). The stability of the flank has been analyzed with Slope/W, using limit equilibrium methods. The analysis of the initial geometry with drained conditions indicates that the flank is stable, with a static safety factor of 1,7 (neglecting any seismic our excess pore pressure effects). Results of various scenarios of failure development have been tested, and show that axial incision appears to be the main instability process, and leads to drained failures. Post-failure evolution has been modeled with Bing software (Imran et al. 2003). Final length and height of the deposit has been analyzed for different initial sliding mass geometries. The analysis has shown that the deposition of soft mudflow layers could only occur by considering superficial failures originating just above the toe of the slope.

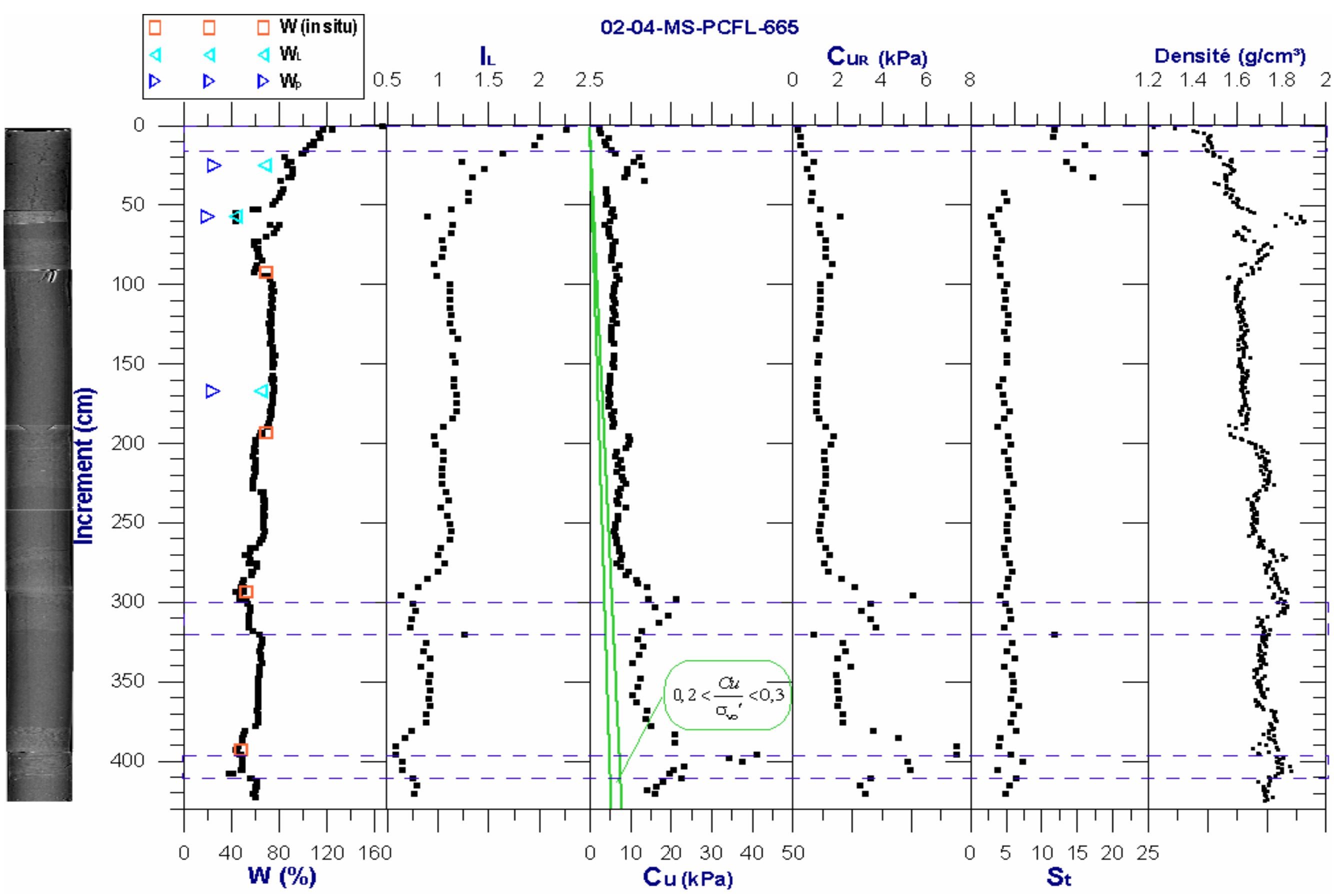

Figure 3. Geotechnical properties of sediment in the lower portion of Cap de Creus Canyon.

IMPACT/APPLICATION

Results obtained in FY06 provide a unique opportunity to clearly demonstrate the potential use of geotechnical profiles to determine the nature of the sediment layer and evaluate their mode of formation. Our results can also be used to improve strength development models used for analyzing sediment accumulation and stability.

TRANSITIONS

Geotechnical profiles, SEM work and cyclic direct simple shear stress tests are used by our partners in assessing sediment formation and, in some cases, evaluating the potential role of gas charging on geotechnical properties. Our CATSCAN analyses and multi-sensor track profiling of various cores illustrate the value of using these non-destructive methods to study sediment architecture and properties. Rheological properties are being used by modelers to represent debris flows (Imran *et al.* 2001). Our work has been presented to offshore research groups interested in margins and in oil and energy development to acquaint them with advances in submarine slope stability and hazard analysis acquired as part of STRATAFORM and EuroSTRATAFORM. We contributed to a major effort in assembling our knowledge on submarine debris flows and their consequences (Locat and Lee 2005) and in risk assessment (Nadim and Locat 2005). We also transferred our knowledge developed as part of STRATAFORM to those interested in mass movement analysis (Locat 2005).

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin that uses techniques produced by STRATAFORM. The development of this project benefited from approaches developed within STRATAFORM. We have been very active in establishing IGCP-511: a UNESCO International Geological Cooperation Program on submarine mass movements and their consequences (2005-2009).

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